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A mmWave Cloud Cooperated and Mobility Dependant Scheme for 5G Cellular Networks

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Abstract*— The unavoidable and dramatic increase of mobile traffic load predicted to hit future cellular networks, has operated as a catalyst for the 5th generation (5G) mobile networks to envision the support of higher data rates by a factor of 1,000 in the next 10 years. The utilization of the ultra-wideband aspect of the mmWave bands has recently risen as a quite promising candidate that could support such an overwhelming demand. Armed with the exploitation of such high frequencies, several studies have proposed a logical split between the control plane (C-plane) operated by macro basestations (BSs) at the 2GHz band and the user plane (U-plane) operated by pico base stations at much higher frequencies (e.g. 3GHz or 60GHz bands). Thus, a heterogeneous cellular network (C-HetNet) is built, where macro and pico BSs could potentially function in a cooperative manner by connecting to a cloud radio access network (C-RAN). Despite the fact that such architecture provides a more efficient approach for handling signalling and user traffic, the use of mmWave bands introduces some major challenges. An appropriate user association scheme is still needed in order to successfully associate a specific user with a particular pico BS before user data transmission is initiated. It is clear that the process followed for user associations and re-associations introduces considerable latency; therefore high user equipment (UE) mobility may negatively affect user experience by demanding very frequent initiations of that process. In this paper, the author proposes a fair, user traffic off-loading mechanism, where highly mobile UEs, after a given grace period, are forced to shift the transmission of user data from the U-plane to the C-plane until the point where they become more stationary. Ultimately, this approach results in a lower amount of user re-associations needed as a trade-off to mobility and in the expense of lower data rates.

Keywords*—*5G; mmWave; heterogeneous network; cloud radio access network; user association; mobility; traffic off-loading

I. Introduction

Due to the current extensive use of mobile user equipment such as mobile phones and tablets that serve the demand for internet connectivity anytime-anyplace, generated traffic loads have dramatically increased in the last 5 years. It is a common understanding that the realization of novel technologies in the area of computing (i.e. Internet of Everything – IoE, Machine to Machine – M2M, Vehicular Networks) will exponentially increase the demand for Internet access and therefore, the corresponding thirst for extremely high channel capacity and data rates is becoming a reality quite rapidly. It is predicted that a system rate improvement of 1,000 times may be required to handle the potential traffic load in the next 10 years.

There are currently 4 different technologies explored in the literature [1], [2] aiming in the realization of an appropriate solution regarding the above described necessity as shown in Figure 1.

a) Enhanced MIMO (Multiple-Input Multiple-Output): multi-layer spatial multiplexing techniques in order to improve spectral efficiency.

b) CoMP (Cooperative Multi-Point Transmission): basestation cooperation for the improvement of number of outages at the outer areas of the cells via inter cell interference alleviation.

c) Heterogeneous Networks: system rate improvement by offloading traffic from macro BSs to pico or femto BSs placed inside the macro BS.

d) Bandwidth Expansion: system rate improvement by aggregating pieces of spectrum in microwave bands.

This paper is based on the technologies described in *c)* and *d)* with some additional functionality from *b)*. The outcome is a cloud cooperated heterogeneous cellular network (C-HetNet) [3] where pico basestations are placed inside the transmission range of macro basestations and all connect together to a cloud radio access network (C-RAN) [4] in order to achieve cooperative operation. Since pico and macro BSs coexist in the same geographical area, a multi band HetNet is therefore created that makes use of low frequencies for the macro

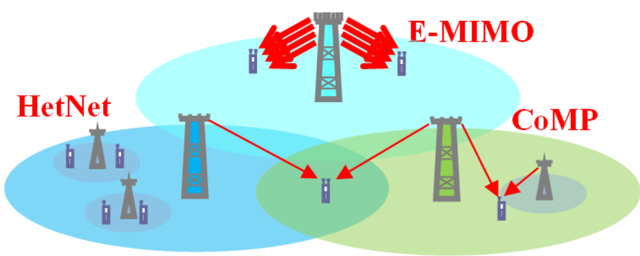

Fig. 1. 5th Generation Cellular Networks.

basestations (e.g. 2GHz) and higher frequencies for the pico basestations (e.g. 3GHz or 60GHz).

Irrespectively of the technology used to increase the system data rate, one of the main functionalities that should be considered is user association (UA) [5]. It is the mechanism used to determine what specific basestation a user is associated with, so as data transmission may commence. In scenarios where user mobility is considerably high and diverse, user re-associations (URAs) and handovers (HOs) may substantially affect the overall network performance by introducing unwanted but also unavoidable delays.

In this paper, a novel 5G cellular network scheme titled C-RAN Mobility Dependant (C-MoDe) is proposed, where user associations and re-associations are best kept to a minimum. Since user mobility is the deciding factor for UAs and URAs to initiate, it is proposed that high mobility should be "punished" with lower available data rates. This is achieved by off-loading data traffic from high capacity channels to lower capacity channels. As a C-HetNet is in operation, the off-loading process is considerably stress free; macro and pico BSs coexist in the same area thus offering the necessary resources for continuous connectivity to all users. UEs that are highly mobile and currently associated with a pico BS, migrate their data transmission towards the macro BS. The result is a fairer approach for more stationary UEs that continue to take advantage of more bandwidth through the pico BSs and the U-plane and on the opposite side, highly mobile UEs downgrade to lower data rates but still remain connected to the network via the macro BS and the C-plane.

The remainder of this paper is organized as follows: Section II presents in detail the C-HetNet architecture that makes use of a cloud radio access network. User association and re-association operations and challenges are discussed in Section III. Section IV describes the proposed novel C-MoDe scheme and analyzes its advantages compared to conventional approaches. Future work and concluding remarks are presented in Section V.

II. CLOUD COOPERATED HETEROGENEOUS NETWORKS

C-HetNets are constructed by making use of two very popular and quite promising cellular network technologies. Those are a) multi-band heterogeneous networks (multi-band HetNets) and b) cloud radio access networks (C-RAN).

A. *Multi-band HetNet*

A multi-band HetNet is a cellular network that operates on multiple frequency bands at the same time and for overlapping geographical areas. Conventional BSs (macro BSs) cover a large area, parts of which may also be covered by low power small coverage area BSs (pico BSs) as shown in Figure 2. Since different frequency bands are used by the macro and pico BSs, there is no need for interference mitigation techniques.

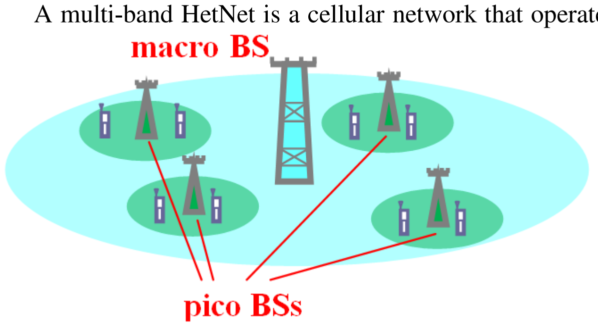

Fig. 2. Multi-band HetNet.

B. *Cloud Radio Access Network*

The concept of C-RAN was first introduced in [4]. Its goal was to address the challenges mobile operators are facing with regards to their radio access networks, such as cost, energy consumption, spectral efficiency, smooth evolution via an open platform for multiple standards support and additional revenue generating services.

C-RAN was proposed to operate following two different methods that consequently offer two separate architectures. The first is a fully centralized solution, where baseband processing takes place centrally for all BSs and the second is a partially centralized solution where baseband processing takes place in a distributed manner and closer to the BSs. Both architectures are shown in Figures 3 and 4. By adopting any of the two available architectures of C-RAN, mobile operators may enjoy multiple benefits but also face important technical challenges.

Advantages include a) energy efficiency/green infrastructure, b) cost saving, c) capacity improvement, d) adaptability to non-uniform traffic and e) smart traffic offloading. On the other hand, mobile operators need to

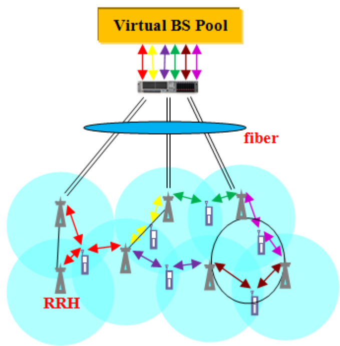

Fig. 3. Fully Centralized C-RAN.

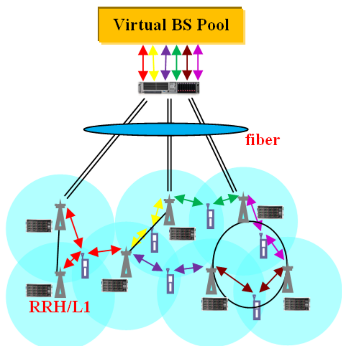

Fig. 4. Partially Centralized C-RAN.

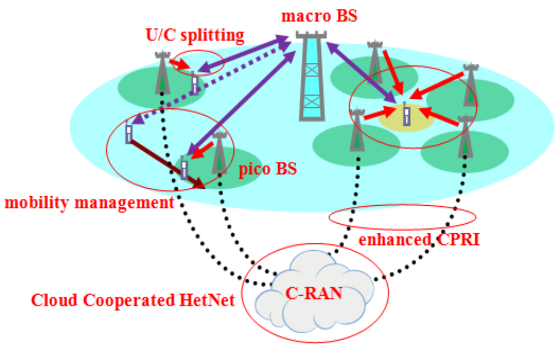

Fig. 5. Cloud Cooperated Heterogeneous Netwotk.

address technical challenges such as a) radio under low cost optical network, b) advanced cooperative transmission and reception, c) baseband pool interconnection, d) basestation virtualization and e) service on edge.

C. C-HetNets

The outcome of combining together HetNets and a Cloud Radio Access Network is the Cloud Cooperated Heterogeneous Network as it is described in [3]. One of the main challenges introduced with multi-band heterogeneous networks is the fact that UEs are required to operate in a multi-band mode as they need to be able to connect to different BSs, transmitting in different frequencies at the same time. Running cell searches for pico BSs quite frequently while connected with a macro BS is extremely power consuming and introduces unwanted overall delay. Furthermore, effective planning for the placement of pico BSs becomes a challenge. Since pico BSs operate in very high frequencies (e.g. 60GHz) path loss is affected by the distance between the UE and the BS with very negative outcomes.

A promising solution to the above issues is the use of C-HetNets as it is presented in Figure 5. According to this architecture, all pico and macro BSs connect to the same cloud radio access network. As a result, the control of all pico BSs is now laid upon the C-RAN of the C-HetNet and is maintained via information provided by the macro BS. As an operating requirement, this approach specifies the splitting of user and control data (U/C splitting). All control traffic between UEs and the network is forwarded to the C-RAN via the macro BS and thus it manages the C-plane for all users. On the other hand, all user traffic (U-plane) is forwarded to the network via the pico BS associated with the particular UE. As a result, the macro BS supports the UE to successfully perform cell searches, handovers and user associations and re-associations with regards to pico BS connectivity.

III. User Association

The overall network performance may be hugely affected by the process of user association, which is the association of a user with a specific BS. Existing wireless technologies make use of a rather simple rule to decide upon what is the best BS for a UE to connect to. A power based approach is followed by the user for UA, where the decision is based on the outcome of the comparison between different received signal strengths as shown in Figure 6. The UE will choose to connect to the BS that provides the maximum received signal strength (max-RSS) as that particular BS is considered to be closer compared to other options. Unfortunately, such a simple methodology is not considered to be very effective when dealing with the unique characteristics of 5G technologies [6]. Since this paper focuses more on the combination of multi-band HetNets and C-RAN in mmWave cellular networks, we will further present the operation of UA and URA with regards to these technologies.

A. User Association in HetNets

In cases where a heterogeneous approach is followed in the deployment of cellular networks and with regard to the UA and URA processes the conventional methodologies are no longer effective. It is not recommended to make use of the maximum received signal strength for a user to associate with a particular BS, as in HetNets macro BSs are meant to transmit with higher signal power compared to pico and femto cells by default. Therefore, a UE would most likely associate with the macro BS, even in extreme cases where the UE is placed exactly next to a pico BS. Only UEs that are placed at the edges of macro cells and at the same time very close to pico BSs have somewhat a greater chance to associate with the later.

In order for the above described problem to be alleviated, 3GPP in Release 10 [7] has proposed a solution that makes use of an artificial bias that is added to the signal strength received by pico and femto cells. Thus, the RSS originating from small cells has a larger chance to alter the comparison that leads to the max-RSS calculation, making it more probable for the UE to associate with a small cell BS rather than a macro BS. The overall result is that more UEs will now be associated with pico and femto BSs compared to when no bias is introduced. Traffic off-loading becomes more balanced and the overall network performance increases rapidly. The disadvantage of such a scheme lays in the increased interference now present between macro and pico cells, due to the signal strength bias added. It seems that there is an obvious trade off between the number of UEs offloaded to the pico BSs and overall network throughput. Clearly, the chosen value of the added bias greatly affects the balance of this trade off making the optimization study for that value a vital process towards an overall satisfactory user experience.

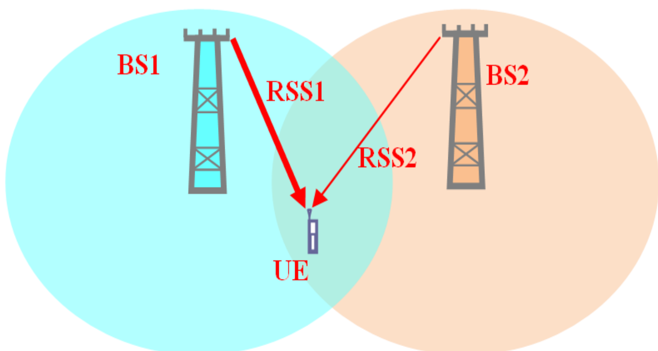

Fig.6. User Association Based on max-RSS.

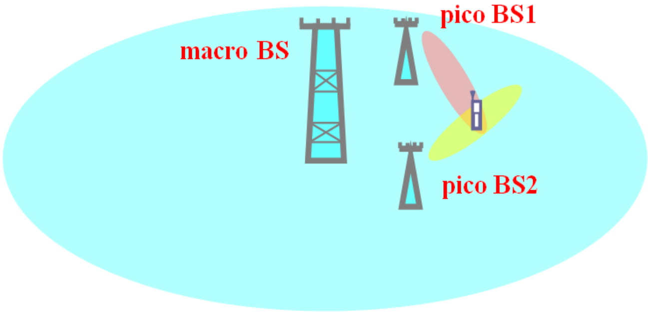

Fig. 7. Number of UAs for highly mobile UE.

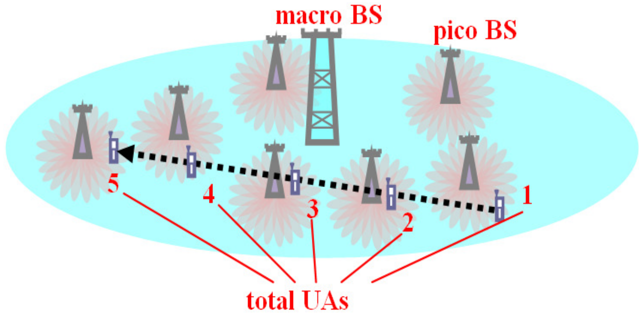

Fig.8. User Association in mmWave Networks.

B. User Association in mmWave Networks

In mmWave networks, the user association and user re-association processes are highly affected by the quality of the offered channel. Therefore, the main characteristics of such networks, namely increased path loss, signal propagation impairments and sensitivity to blockages, play a pivotal role in the selection process of a user to associate with a particular BS [8] as shown in Figure 7.

At this point it is critically important to mention that there is a fundamental difference in UA between heterogeneous networks and mmWave networks. Despite the fact that in both cases pico cells are deployed inside the same geographical area that a macro cell operates, in heterogeneous networks as explained in Section II, since both pico and macro BSs operate in similar frequencies there is significant interference between them. On the other hand, in mmWave networks, pico and macro BSs operate in different bands and as a result no interference mitigation schemes are needed. The problem here is the difficulty in cell coverage due to mmWave channel characteristics.

It remains inefficient to base the UA and URA processes on RSS values as handovers are likely to take place very frequently, having as a result the dramatic increase in delays and overall network performance degradation. Despite the fact that there are proposed approaches in the literature on how to associate a user to a BS in mmWave networks, this is still an uncharted area that requires a lot of attention from the research community.

IV. Cloud Cooperated and Mobility Dependant Scheme

Mobility support when dealing with cellular networks that are deployed as HetNets with mmWave characteristics, requires a lot of attention, as there are many challenges that need to be addressed.

Consider the scenario where a HetNet is deployed with macro BSs operating in conventional 4G/LTE bands and pico BSs operating in millimetre wave bands are placed inside the macro cell. All individual users will attempt to associate primarily with a pico BS and if that is not possible then they will attempt to associate with the macro BS so that connectivity is maintained. Due to the propagation and beam forming characteristics of mmWave networks, it is impossible for users with medium or high mobility to maintain connectivity with a specific pico BS for long time periods. Such high mobility users are required to initiate the process of UA and URA multiple times in short periods as they may frequently migrate from pico to pico cells and from pico to macro cells as presented in Figure 8. A conventional UA and URA algorithm that does not take into account the mobility of UEs may result in unacceptable levels of overhead that in turn introduce extremely high traffic delays that affect the overall network performance and ultimately user experience. Such effects of performance degradation are experienced by all users whether they are highly mobile or not.

In this paper we propose a mmWave, Cloud Cooperated and Mobility Dependant (C-MoDe) 5G network scheme based on C-HetNets as they were presented in Section II. The aim of C-MoDe is to reduce the amount of UAs and URAs needed by highly mobile users and thus increase overall network performance. This becomes possible by intentionally creating a trade-off between the level of user mobility and provided data rates. The details of this scheme are presented in Figures 9 and 10.

According to C-MoDe, a UE is required to count the number of UAs and URAs performed by itself within a fixed period of time (*timeout*) and save information about all of them in an internal data structure (*UserA.Table*). Old entries are deleted and replaced by new entries as the user moves from cell to cell. The total number of entries in this data structure is representative of the user's recent mobility level. Initially, the UE attempts to associate with a pico BS and in case this process is successful, it starts recording its mobility. In case the recorded number of recent associations reaches a pre-determined threshold (*c_threshold*) then the user will shift its data transmission from the U-Plane to the C-Plane. As a result, associations will now be performed only when the user migrates between macro cells and the value of the associations

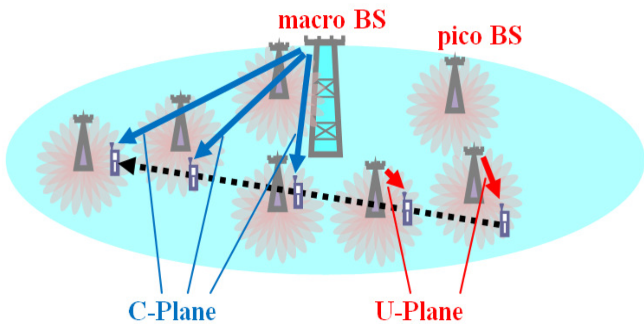

Fig.9. C-MoDe Operation.

```
c_threshold=value1;
count=0;
t_threshold=value2;
timeout=value3;
timer=current_time;
create UserA.Table(BS, time);
/*** Initiate Grace Period ***/
sleep(value4);
/*** Start Process ***/
while(1)
{
    if(current_time-timer>t_threshold)
        start UserA.Process;
    if(UserA.Process==1)
    {
        shift data transmission to U-Plane;
        find empty space in UserA.Table;
        insert UserA.Table(UserA.Process(BS,
        current_time);
        for(every entry in UserA.Table)
        {
            if(UserA.Table.time<current_time-timeout)
                delete entry in UserA.Table;
            count++;
        }
        if(count>c_threshold)
        {
            shift data transmission to C-Plane;
            timer=current_time;}
}   }
```

Fig.10. C-MoDe Algorithm.

counter (*count*) will eventually decrease. Consequently, the UE will be given an extra chance to associate with a pico BS and therefore increase its data rate by off-loading its traffic back to the U-Plane when the value of *count* becomes lower than the threshold. The entire process continues for as long as the UE remains active in the network, switching its traffic load between the U-Plane and the C-Plane based on its recent mobility level.

The outcome of C-MoDe is a fairer approach towards more stationary UEs as they are not likely to off-load their traffic from the U-Plane to the C-Plane and therefore they continuously take advantage of the very high data rates offered by the pico BSs whenever they become available. On the other hand, highly mobile UEs are "punished" for the increased overhead they produce to frequently associate with pico BSs, with lower data rates offered by the macro BS. This "punishment" is not very long lasting, as extra chances are offered to these UEs to re-associate with a pico BS when the *timeout* period has passed and continue enjoying high data rates if they prove to have become more stationary.

V. Conclusion & Future Work

Concluding remarks and future work are presented in this section.

A. Conclusion

In this paper a new mmWave Cloud Cooperated and Mobility Dependant (C-MoDe) scheme for 5G cellular networks was proposed to reduce the overall required amount of UAs and URAs and thus to increase overall network performance. C-MoDe takes advantages of the U/C splitting mechanism and off loads data traffic coming from medium and highly mobile users to the C-Plane. Due to the fact that the coverage area provided by macro BSs is much larger compared to that of pico BSs, these users will remain connected solely to the C-Plane and eventually will be given an extra chance to reconnect to the U-Plane and continue to remain connected having to prove that they have now become more stationary. As a result, the overall number of UAs and URAs performed by all UEs in the network is reduced to a minimum required in order to maintain connectivity, always in favour of more stationary users that enjoy continuously high data rates provided by the U-Plane.

B. Future Work

- Perform extensive simulations in order to demonstrate the validity of the proposed scheme.
- Investigate the effect of specific values for important algorithmic parameters such as c_threshold, t_threshold and timeout.
- Implement the proposed scheme for a variety of different scenarios in order to present the effect of different UE speeds and UE and BS density levels on overall network performance.

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